Solar eclipse: The rise and 'dusk' of the Dutch PV innovation system

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Abstract: In this paper, we take the theoretical perspective of innovation system dynamics and apply this to Photovoltaic (PV) solar energy technology in the Netherlands. The history of the development of the PV innovation system is analysed in terms of seven key processes that are essential for the build-up of innovation systems. We show that large fluctuations are present in the processes related to guidance of the search and market formation. Surprisingly, entrepreneurial activities are not too much affected by fluctuating market formation activities. We relate this to market formation in neighbouring countries and discuss the implications for policy making.

Keywords: PV; photovoltaic; innovation system dynamics; motors of innovation.

Reference to this paper should be made as follows: Negro, S.O., Vasseur, V., van Sark, W.G.J.H.M. and Hekkert, M.P. (2012) 'Solar eclipse: The rise and 'dusk' of the Dutch PV innovation system', *Int. J. Technology, Policy and Management*, Vol. 12, Nos. 2/3, pp.135–157.

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1 Introduction

It is widely recognised that the dominance of fossil fuels in the world energy system causes severe environmental problems, such as climate change. However, the diffusion and implementation of alternative technologies, such as renewable energy technologies that would at least partly solve this problem, proceeds slowly. New technologies have to compete with an incumbent technological system that is locked in the use of fossil fuel (carbon lock-in) and that benefits from long periods of experience, leading to high efficiency, low costs, optimal institutional arrangements, and many vested interests (Unruh, 2000). These renewable energy technologies, on the other hand, are in their early phases of development and therefore, still inefficient and badly adapted to the function they need to fulfil in society. This makes rapid diffusion a very difficult process (Rosenberg, 1976).

A relevant question, therefore, is: how do we break through the lock-in situation, and create a situation where renewable energy is widely used in society? To answer this question, it is necessary to open the black box of carbon lock-in, and to analyse in a detailed manner how the development and diffusion of renewable energy sources takes place. Such an analysis should also allow us to pinpoint key mechanisms that block or induce this development process. Insight into these mechanisms is necessary to design policy arrangements that can efficiently deal with these blocking and inducement mechanisms, to speed up the diffusion process of renewable energy technologies.

For opening the black box and analysing the development and diffusion process of renewable energy technologies, many different perspectives can be used. In this paper we use the framework of Technological Innovation System (TIS). This framework has been developed over the last few years, and nowadays, it is often applied to analyse technological transformation processes (Hekkert et al., 2007; Negro et al., 2007; Bergek et al., 2008). The strength of the framework is that it takes a system perspective to explain how different structural components of the innovation system (technology, actors, networks and institutions) influence the development and diffusion of a specific technology.

In this paper, the specific technology that will be analysed is Photovoltaic (PV) solar energy technology in the Netherlands. The reason for this is that there is a long history of policy efforts in the Netherlands to stimulate PV, but results in terms of diffusion of PV panels in the Netherlands are disappointingly low, which clearly constitutes a case of slow diffusion. Nonetheless, new silicon production plants or module assembly plants are being constructed. This could be due to the rapid growth of the global market in general, and in particular, those of neighbouring countries such as Germany, which is home to the largest PV market. The growth in the European market has been principally driven by the dynamism of the German market (Vasseur and Kemp, 2011). In this case study, we will pay particular attention to the influence of neighbouring markets and assess how they influence diffusion and policy processes in the Netherlands. Therefore, the research question that will be answered in this paper is:

What are the barriers that hamper the build-up of the Dutch PV innovation system and what are the implications for policy?

In the next section, the theoretical framework will be described in more detail. Section 3 provides insights into the methodology used to identify the barriers for the development of PV. In Section 4 the development, diffusion and decline of PV technology in the Netherlands will be elaborated upon and analysed. Section 5 will conclude this paper by answering the above mentioned research question and discussing the policy implications.

2 The functioning of technological innovation systems

The theoretical framework used to analyse the evolution of PV in the Netherlands is that of an emerging Technological Innovation System (TIS). A TIS is defined to comprise a set of actors and institutions whose actions and interactions contribute to the development and diffusion of a new technology. Institutions are in this case the rules of the game, and consist of formal institutions (e.g., regulations) and informal institutions (e.g., values, expectations). When a TIS starts to emerge, very few actors are involved who put efforts into developing the technology in question. As time goes by and success occurs, the TIS is likely to grow in number of actors, strength of networks and in terms of institutions aligned to support the new technology (Hekkert et al., 2007; Van Sark et al., 2007; Hekkert and Negro, 2009). This is called the formative phase of a TIS (Jacobsson, 2008).

Recent studies have shown great progress in understanding this formative phase of a TIS (Hekkert et al., 2007; Jacobsson, 2008; Hekkert and Negro, 2009). The basic conclusion that follows from these studies is that a number of key processes need to take place in a TIS in order for the system to grow in terms of structural elements (Edquist and Johnson, 1997; Galli and Teubal, 1997; Johnson, 1998; Jacobsson and Johnson, 2000; Liu and White, 2001; Rickne, 2001; Bergek, 2002; Jacobsson and Bergek, 2004; Carlsson et al., 2004; Hekkert et al., 2007; Negro et al., 2007). These processes are often labelled as functions of an innovation system (or system functions). Based on Hekkert et al. (2007), We discern the following system functions (see Table 1).

Table 1 System functions of technological innovation system

Function	*Description*
Function 1: Entrepreneurial activities	The existence of entrepreneurs in innovation systems is of prime importance. The role of the entrepreneur is to turn the potential of new knowledge development, networks and markets into concrete action to generate and take advantage of business opportunities
Function 2: Knowledge exchange	Mechanisms of learning are at the heart of any innovation process. Therefore, R&D and knowledge development are prerequisites within the innovation system. This function encompasses ‘learning by searching’ and ‘learning by doing’
Function 3: Knowledge diffusion through networks	The essential function of networks is the exchange of information. This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government, competitors and market. Network activity can be regarded as a precondition to ‘learning by interacting’. When user producer networks are concerned, it can also be regarded as ‘learning by using’
Function 4: Guidance of the search	The activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users fall under this system function. Expectations are also included, as occasionally expectations can converge on a specific topic and generate a momentum for change in a specific direction
Function 5: Market formation	A new technology often has difficulties to compete with incumbent technologies, as is often the case for sustainable technologies. Therefore it is important to create protected spaces for new technologies. One possibility is the formation of temporary niche markets for specific applications of the technology. This can be done by governments but also by other agents in the innovation system
Function 6: Resources mobilisation	Resources, both financial and human, are necessary as a basic input to all the activities within the innovation system
Function 7: Creation of legitimacy	In order to develop well, a new technology has to become part of an incumbent regime, or has to even overthrow it. Parties with vested interests will often oppose this force of ‘creative destruction’. In that case, advocacy coalitions can function as a catalyst to create legitimacy for the new technology and to counteract resistance to change

Both the individual fulfilment of each system function and the interaction dynamics between them are of importance. When more functions are fulfilled, the expectation is that there will be a better performance of the TIS, which results in higher chances for successful development, diffusion and implementation of new technologies. The different system functions can influence and reinforce each other, which results in different functional patterns. In his PhD thesis, Suurs (2009) has labelled this process as 'motors of innovation'. These motors of innovation help to explain TIS build-up around sustainable energy technologies. Suurs (2009) identified five motors, see Table 2, were each is characterised in terms of dominant functions and interactions between these functions.

Table 2 Motors of innovation

Motor	*Description*
Motor 1: Science and technology push motor	The first and least developed motor is dominated by the functions knowledge exchange (+F2) and –diffusion (+F3), guidance of the search (+F4) and resources mobilisation (+F6). The role of entrepreneurial activities (+F1) and the creation of legitimacy (+F7) played also a role but it is typically weak or even absent. This motor is expected to precede the initiation of a project, because it is plausible that a certain knowledge base and expectations are required before a complex project is initiated; the Science and Technology Push motor can provide this
Motor 2: Entrepreneurial motor	The more elaborate entrepreneurial motor is stressed to replace the science and technology push motor, maintaining its virtuous cycle and adding to it the functions creation of legitimacy (+F7) and entrepreneurial activities (+F1). The cumulative causation is created by new entrants or diversifying incumbent actors that start experimenting (+F1), positive expectations (+F4) in turn leads to lobby activities for support (+F7) from other actors (e.g., government) to mobilise resources (+F6), which in turn leads to more entrepreneurial activities (+F1)
Motor 3: System building motor	This motor resembles the entrepreneurial motor with some changes; it includes a more important role of market formation (+F5). The main difference lies in the connection between creation of legitimacy (+F7), on the one hand, and market formation (+F5) and guidance of the search (+F4) on the other. Outsiders are increasingly involved in networks by enacting new entrants, governments, intermediaries and stakeholders in their system. From this network, outsiders attempt to develop the innovation system by enhancing the motors virtuous cycles
Motor 4: Market motor	The market motor is characterised by a strong fulfilment of all functions, except the creation of legitimacy (+F7) is not strongly fulfilled. This function is not as important for this motor because market formation (+F5) is no longer a political issue. The market environment has been created as the result of formal regulations. Market formation (+F5) is taken up as part of regular business activities (i.e., marketing activities and promoting strategies) that are directly connected to entrepreneurial activities (+F1)
Motor 5: Motor of decline	This motor does not explain structural barriers that block motors of innovation; it shows event sequences that constitute an accelerated breakdown of TIS structures

Source: Based on Suurs (2009)

Motors of innovation cannot be regarded as independent of the structures of a TIS. On the contrary, motors of innovation emerge from a configuration of structural factors, and in turn rearrange that configuration. There exists a mutual relation between the structural configuration of a TIS and the system functions which are fulfilled in it. For the purpose of this paper, the focus will be on the dynamic aspect, i.e., the system functions. Some motors of innovation and their connection to factors internal to a TIS will be identified.

However, external factors such as, for example, the development of foreign PV markets, are important as well. They will be considered as a part of the analysis wherever they affect the dynamics of the TIS (Suurs and Hekkert, 2009b).

The aim of the paper is to identify motors of innovation of the PV TIS and provide handholds for policy making to accelerate the diffusion and implementation of PV technology in the Netherlands.

3 Research methodology

The method used to map interaction patterns between system functions is inspired by the process method used by Van de Ven and colleagues (Van de Ven et al., 1999; Poole et al., 2000). Stemming from the organisational theory, the usual focus is on innovation projects in firms and firm networks; in our case, the analysis is applied to a TIS level (for a more extensive description of the methodology, we refer to Negro (2007), Negro et al. (2007), Negro and Hekkert (2008) Suurs and Hekkert (2009b)).

Basically, the approach consists of retrieving as many events as possible that have taken place in the innovation system using archival data, such as newspapers, magazines, reports and interviews with experts of the field. The events are stored in a database and classified into event categories. Each event category is allocated to one system function using a classification scheme (see Appendix 1). These events can then be plotted in graphs per year and per system function. Here, only the occurrence (+ or –) of the event rather than the content is represented (see Appendix 2 for an overview of all system functions of the Dutch PV TIS).

The contribution of an event to the fulfilment of a system function may differ considerably from event to event. Some events have a positive contribution, such as the opening of a large-scale building-integrated PV project, while others contribute negatively, as for instance an expression of disappointment, or the opposition of an important political group. This is indicated in the allocation scheme by +1 and –1. The final outcome of the process analysis is a narrative (storyline) of how the development of the TIS has changed over time and the role of the different system functions within this development. In the narrative, the focus is on extracting motors of innovation. Based on the content of the events and their chronological order, we are able to deduce the effect of one event on another and the order in which such events occurred. By observing reoccurring sequences of events, we are able to identify motors of innovation.

4 Historical overview of PV in the Netherlands from 1970–2010

In this section, a chronological description of the events that took place in the PV trajectory is presented. The description will be subdivided into different year periods. The end of each period is chosen on the basis of change in activities or key events and therefore, not all periods are of equal length. The symbols F1–F7 refer to the seven system functions, as described in Section 2. In Appendix 2, an overview of all events plotted per function per year can be found. By comparing the shape of the lines of each system function with the storyline, patterns and cycles can be identified. The content and, thereby, the relative impact of the event on system function fulfilment, is subsequently elaborated upon in the narrative.

4.1 The dawn of PV in the Netherlands (1970–1994)

The interest in PV as an alternative energy source started in the Netherlands in the 1970s, due to the oil crises. Dutch policy makers become aware that the Dutch economy is too dependent on fossil fuels and that a diversification strategy is necessary. The Dutch government publishes two 'Energy White Papers' in 1974 and in 1979 that clearly state the need for alternative energy sources (+F4). In the energy research community, these signals are picked up, and research projects start to explore PV technology. The research leads to positive outcomes (+F2) which influence scientists to lobby for the expansion of fundamental research on PV and its acceptance as a renewable energy source (+F7). Within this lobby, the Dutch Solar Trade Association 'Holland Solar' is founded in 1983, which will become a primary sparring partner for the Ministry of Economic Affairs. The members of the association are companies or organisations active in the field of solar thermal energy or photovoltaic solar energy for small- and large-scale applications; they lobby strongly with the government (Reinshagen, 1984; Bokhoven, 1987; Verbong et al., 2001; HollandSolar, 2007). The Dutch government is susceptible to this lobby, and by the end of 1984, a coordinated programme starts for fundamental PV research at three Dutch universities, together with Dutch members of the 'International Solar Energy Society' (ISES),[1] the so-called ISES-programme (+F4) (Duurzame Energie, 1987; Verbong et al., 2001). Over the years, the popularity of PV within the government continues to grow and in its budgets, the Ministry of Economic Affairs pays more attention to research on PV conversion (Blok, 1985). In 1986, the National Research Programme on PV[2] (with a budget of 2.7 million Euros) is started (+F2), aiming to follow international activities concerning PV by building up and maintaining expertise on several specific areas that are already present in the Netherlands. Another goal is also to promote the development of PV conversion concerning future energy provision in the Netherlands (Duurzame Energie, 1987; Verbong et al., 2001).

Towards the end of the 1980s, there is a temporary reservation of the national government towards PV, as it doubted whether PV is a suitable renewable energy technology for the Netherlands (–F4). The doubts are related to the issue of whether the Netherlands are sunny enough for PV to generate substantial amounts of power and to the question of how to fit PV into a strongly centralised energy system. Ultimately, PV gets the benefit of the government's doubts, and the Dutch government starts to develop instruments to create a market for PV. They implement the "Support Regulation Energy Savings and Flow Energy" (SES)[3] in 1988, and will renew it in 1991. This regulation states that 40% of the purchase costs of a PV system are compensated (Natuur & Milieu, 1990; Duurzame Energie, 1991) (+F5). Further support for PV is provided in the "White Paper on Energy Savings"[4] published in 1990. The goal is that in 2010, PV has to replace 2 PJ of fossil fuels, which is equal to 240 MWp of PV modules (+F4). This is the first time that a specific aim is formulated for PV. This is a clear response to high oil prices (Min, 1993; EnergieNed, 2000; Verbong et al., 2001). Additional policy documents by the government and the statements of the distribution companies to further support PV are published in the coming years (+F4), which are a strong indication for insiders that they are on the right track. This triggers their expectations, and they start to carry out more research (+F2) to contribute to an efficiently working PV technology. The "Energy research Centre of the Netherlands" (ECN) starts to cooperate with a large number of Dutch as well as foreign parties, originating from both the research world and the industrial sector. These research groups have an important role during this phase of the

PV innovation system. In 1994, ECN and the company R&S (Verbong et al., 2001)[5] produce an industrial PV module with an efficiency of 16% (+F2), and R&S starts a pilot production line for multi-crystalline silicon PV (+F1). The Netherlands acquire an important position in the global PV research world with these technological improvements (Duurzame Energie, 1994; Energie and Milieu, 1994). This leads to pilot projects set up by several Dutch Universities (+F2), where PV is placed on house roofs (e.g., Castricum, Amersfoort-Nieuwland, Heerhugowaard-City of the Sun, Barendrecht) (+F1) (Schoen, 2001; Verbong et al., 2001). These projects not only lead to knowledge development on PV system performance (+F2), but also guide the search by highlighting the importance of this technology (+F4).

The dynamics characterising this first period involve positive expectations (+F4) leading to the setting up of several R&D programmes, and directly linked to it, the allocation of financial resources (+F6) to PV. More specific budgets and support and legitimacy from industrial parties (e.g., R&S) result in a boost to activities in the form of feasibility studies by several Dutch Universities (+F2), the first entrepreneurial experiments (+F1) and also cooperation between research institutes and industrial parties (+F3). Thus, here we observe a first motor of innovation, labelled as *Science and Technology Push (STP) Motor*, given the dominance of scientists and technology developers in developing PV.

4.2 The sunny side of the PV innovation system (1994–2000)

This period is marked by the introduction of the 'Third Energy White Paper' (EZ, 1995)[6] in 1995 (+F4), where the aim is to achieve a 10% share of renewable energies in 2020. PV comes on third place as an important renewable energy technology, but its actual impact will be for the long-term (EZ, 1995). To achieve the goals of market formation and energy saving, several generic programmes and policies for renewable energies are set up (+F5, +F6) (see Table 3 for an overview of the programmes and policies).

However, these programmes and measures are not specific for PV. Therefore, SenterNovem, on behalf of the Ministry of Economic Affairs, starts to prepare the follow-up for a third national research programme on PV (NOZ-PV 96-00), which will run until the year 2000 (+F6). This research programme is more market oriented than the previous two programmes. The main aim of the programme is the realisation of conditions and the removal of bottlenecks in the large-scale implementation of PV panels in the Dutch energy system in the 21st century (Duurzame Energie, 1995a; Roos and Blom, 2001). Further targets for market development are set in 1997, when the 'PV Covenant' is voluntarily signed by several players in the PV field, e.g., SenterNovem, the Ministry of Economic Affairs, a number of utilities and property developers, building material manufacturers, the PV industry, research institutes, consultants and others (+F4) (Schoen, 2001). It functioned as a useful platform to transfer knowledge, because of the diverse parties involved trying to influence national policy (+F3) (Duurzame Energie, 1997).

The programme and the covenant galvanise entrepreneurs into becoming more active (+F1) and starting the development of a Dutch PV market (+F5). R&S becomes Shell Solar Energy BV and opens a new production line for multi-crystalline silicon PV panels with a capacity of 2.5 MWp per year, with the intention of expanding within a period of five years to approximately 20 MWp per year (+F1) (TW, 1997a, 1997b; Duurzame Energie, 1997b). In the same year, the 'City of the Sun' on the Vinex location between

Heerhugowaard, Alkmaar and Langedijk (HAL location) start thinking about the construction of an emission free city, including up to 5 MW PV (+F1) (EnergieVerslag, 1997). The costs are 30 billion euros (60 billion guilders), making it the largest PV project in the world (Duurzame Energie, 1997c). In this project, the local government is the main initiator, while that role in other projects (e.g., Nieuw Sloten and Nieuwland in Amersfoort) is mainly played by energy distribution companies (Duurzame Energie, 2000). Further, NGOs start to become active and behave like real entrepreneurs: Greenpeace starts the 'Solaris' project (1998) which offers customers a complete PV module for 500 Euros (+F1). Together with another programme 'PV GO!' (SenterNovem; DE, 2003a; Sinke et al., 2008),[7] they install PV modules on more than 3000 houses (see Figure 1 for an increase in installed capacity) (Duurzame Energie, 2000a; Schoen, 2001). The realisation of these projects together can be seen as an attempt to create a mass market for PV in the Netherlands by lowering prices due to benefits of scale and learning experiences. At the same time, the research in the Netherlands focuses on several items which are closely linked, namely, cost reductions, performance improvements and integration into buildings.

Table 3 Overview of programmes and policies

Period	*Financial stimulation*	*Aim*
1996–2003	REB	To reduce the energy use of companies and households. It comprised a tax on the use of energy
1996–2003	VAMIL	To accelerate depreciation of investment which were included on the energy list
1996 – still running	EIA	To offset investments in technologies against taxable profit which were included on the energy list
1996–2004	BSE	To stimulate the use of sustainable energy and environmental energy technologies by providing subsidy for research and development projects in the field of renewable energy
1996 – still running	Green Funds	To stimulate private investments in environmentally friendly projects like PV by means of a tax exemption of this interest
1997–2000	EBF	To give the possibility to lean money for investments in energy saving technologies against a lower interest (3%)
1997–2004	EET	To come to a solution of the CO_2-problem by development and application of new and innovative technologies

The event sequence of this period is characterised by an initial impulse of multiple system functions simultaneously, where entrepreneurial activities (+F1) serve as a pivot in the unfolding of more positive dynamics. The PV covenant and several research and market formation programmes trigger entrepreneurs into setting up pilot projects on house roofs and for R&S to expand their production line. As the entrepreneurial activities have a pivotal position, we observe an *Entrepreneurial Motor*. It differs from the STP motor, where the entrepreneurial activities are an important outcome, but are not so much an essential driver of further developments. The Entrepreneurial Motor builds for a large part upon the technological and institutional progress established by the STP motor.

4.3 The 'dusk' of the PV innovation system (2001–2003)

This period is marked by a large political shift, as the national government changed its policy concerning renewable energies (PV-Nieuwsbrieven, 2002/2003). Since the main contribution to the 10% target is expected to come from wind energy and biomass, it is decided that all dedicated (R&D, demonstration and market development) programmes for other renewables, such as thermal solar energy and PV, will be ended (–F5, –F6) (Sinke, 2002). In addition, on the first of July 2001, the energy market is liberalised (Duurzame Energie, 2001a). From this moment on, PV has to compete in a free market with cheap fossil fuels and other renewable energy options. It is feared that the diffusion of PV could be endangered, but in contrast to other renewable energy technologies (such as biomass digestion or gasification that collapsed after the liberalisation (Negro et al., 2007, 2008)) the installed capacity of PV continues to grow (see Figure 1). This can be explained by the "Energy Contribution Regulation" (EPR)[8] that stimulates people to buy energy efficient equipment and to produce green energy by giving subsidy (+F5) (Duurzame Energie, 2002a, 2003). Additionally, the support from environmental organisations (Greenpeace, WWF) and energy distribution companies (Nuon and Eneco Energy) contribute to the diffusion of PV in the Netherlands. Also, the market for small-scale PV systems is boosted by dedicated campaigns of municipalities, some of them offering extra subsidies. For example, the programme 'ZonZeker' by the Province of Groningen, together with Essent, stimulates consumers into buying PV modules and boilers (+F5) (Duurzame Energie, 2001c), and the programme "More roofs under the sun" (Novem) stimulated house building agencies to include PV in their constructions (+F5) (Duurzame Energie, 2004b). Together, these activities reinforce and legitimise the use and diffusion of solar energy in the liberalised energy market (Sinke et al., 2008).

So far so good; it seems that the previously build-up Entrepreneurial Market is strong enough to withstand changes within the institutional setting and that enough support and momentum is present to move from an Entrepreneurial Market to a System Building Market. However, several crucial events happen in the next two years and provide a serious blow to the PV TIS, though not without the PV sector 'fighting back' until the bitter end.

First, in December 2002, Shell Solar announces the closing of the PV plant in Helmond (–F1); one reason being that they want to concentrate their activities in North America, Germany and Portugal due to attractive regulations and high demand in these countries. A second reason is to streamline production after starting a joint venture between Shell Solar Energy and Siemens (Duurzame Energie, 2002c, 2004). With the closure of the plant in Helmond, the production of solar panels decreased to practically zero in the Netherlands, and all knowledge, expertise and skills are leaving the Netherlands. A new plant is being built in Germany using knowledge generated in the Netherlands (TW, 1997a, 1997b; Duurzame Energie, 1997b). The interest in other countries can be explained by the growth of the worldwide PV market.

Second, despite the success of the EPR programme, which led to an increase of the total installed capacity of PV in the Netherlands, the programme is ended due to several reasons:

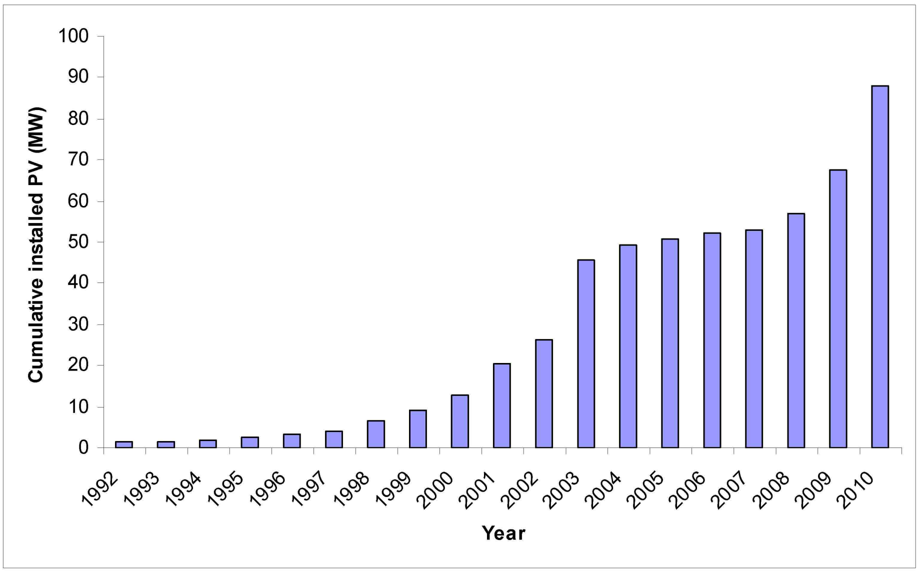
- the budgets of the EPR were insufficient
- inflated subsidies[9] and free-riding behaviour[10]

- bad monitoring by the government in the years 2001–2002, with the consequence that far more subsidies were granted than the available budget could provide.

Adding up all these reasons led the government to announce the discontinuation of the EPR within a month (–F4, –F5), due to its large success. This announcement results in a 'gold rush' by actors in the PV sector to exploit this subsidy as long as it lasted; in that last month, about 90,000 PV panels are sold to households (about 8 million kWh per year, corresponding to a consumption of 2500 households), for a value of 100 million Euros (YourEnergy.net, 2008; PV-Nieuwsbrieven, 2002/2003; Duurzame Energie, 2003; SenterNovem n.d./2010). This huge run is responsible for the peak installation of PV in the Netherlands in 2003 (see Figure 1), before its collapse.

After this rush, expectations are very low as thousands of jobs (installers and consultants), the knowledge about the technology and installation will be lost (Volkskrant, 2003). This will also lead to reluctance in the business sector to make investments in solar energy (–F6), and a drop in net sales (HollandSolar, 2007). The PV Covenant is also not extended because of overly high demands for financial support of the industry (–F3).

Figure 1 Cumulative installed PV in the Netherlands per year (see online version for colours)



Summarising, this period is dominated by the unpredictability of the government, which explicitly removes all support for PV, and the liberalisation of the energy market, combined with a simultaneous rapid growth of the global PV market. This results in decreasing investments in the Dutch PV sector, and a shift by investors, manufacturers and entrepreneurs towards the worldwide PV market, where they look for support and collaboration on an European level, or for financial support from neighbouring countries (for example, municipalities in Germany). This shift also leads to a great loss of employment and knowledge, skills and expertise in the sector. With the final removal of the subsidies, the gold rush towards the installation of PV panels collapses. This results in a collapse of the Dutch PV innovation system, as the previous positive motors of innovation transform into a motor of decline. The impact of a motor of decline on TIS structures is clearly the deterioration of the TIS, in terms of technologies, infrastructure and important institutions, and most especially, in terms of the involvement of insiders. After all, as technological promises are broken, the set of cognitive rules is bound to change, which is not something that can be changed easily, as it is based on trust (Suurs, 2009).

4.4 Recovery of PV in the Netherlands (2003–2010)

Notwithstanding these blows, advocates and insiders of the technology reorganise themselves to launch new lobbying activities and experiments to show that PV is still an option. Dutch entrepreneurs notice the upcoming foreign market and try to remain in the race as a leading country in terms of knowledge and technology production. This leads to a boost in activities by Dutch entrepreneurs concentrating on export markets such as Germany and Spain, as these latter countries enjoy favourable financial stimuli (such as high feed-in tariffs) for PV (HollandSolar, 2007). Solland Solar for example, is located in Heerlen/Aachen (the so-called Avantis Park) on the border between the Netherlands and Germany, and obtains subsidies from two countries (Stromen, 2004a, 2004b).

The faith of entrepreneurs and industry in a sunny future for PV panels continues when a ‘Roadmap Solar Energy’ is developed in 2005 by Holland Solar (Dutch PV association) in collaboration with the Dutch PV sector. The roadmap puts forward a vision for the future of PV and the steps for further market development (+F3, +F4) (Bode, 2005; HollandSolar, 2007). It is also one of the documents used as basis for a PV transition path (Sinke et al., 2008). This roadmap is offered to the government as input to formulate a common vision (Sinke et al., 2008). However, with the fall of the government in 2006, the vision is not included in its future agenda and on top of that, the temporary Minister of Economic Affairs ends the “Environmental Quality of the Electricity Production” (MEP)[11] in August 2006, without warning. The official reason is that the goal of 10% renewable energy in 2010 will be achieved easily without subsidies, whereas the actual reason is supposed to be (again) the expiration of the governmental budget (–F5) (Energie+ 2006). Nonetheless, Holland Solar continues lobbying activities and believes that solar energy could still contribute to the renewable energy supply of the Netherlands. However, the lobby power of the insiders and outsiders in favour of PV is limited, previous documents and agreements are ignored by the government, and their wishes and ideas regarding market strategy are not taken into consideration. The government mainly sees a role for PV in the far future, i.e., after 2020, as the expectations are that PV will reach consumer price levels only over 10 years of time (Montfoort and Ros, 2008). Therefore, only R&D activities (+F2, +F3) are supported and financed by the government for the most part (EOS programme (SenterNovem; Sinke et al., 2008))[12] (+F6).

After the gold rush, researchers go back to the drawing table to do further research to reduce costs and be less dependent on high subsidies. In the meantime, production activities in the Netherlands (i.e., Solland Solar) continue due to export. Due to the strong presence of support from advocacy coalitions by Holland Solar (+F7), and especially due to entrepreneurial activities (+F1), some outsiders (e.g., Derbisolar, Triodos, Henderson global investors) are incorporated into the PV TIS. This in turn affects the build-up of a broad base of insiders, including local governments, supply-side and demand-side firms.

In 2007, a new government is installed which announces an ambitious sustainability plan aiming at an annual energy consumption reduction of 2%, a CO_2 emission reduction of 30% by 2002 compared to 1990, and a contribution of 20% of renewable energy production in 2020 (Coalitieakkoord, 2007; Bundy, 2008; Sinke et al., 2008). Following these ambitions, the government sets up a new market implementation programme, called "Stimulation of renewable energy production" (SDE)[13] (+F5). One month after the implementation of this programme, more applications are submitted than the money available will support (17.8 MW instead of 10 MW) (NWEA, 2008; ODE, 2009). Due to this overwhelming public interest, an additional budget is allocated in 2009 to allow another 11.8 MW to be installed over the coming years. The adjusted SDEs are available for small-scale as well as for larger scale PV installations (15–100 kWp) (Senternovem, 2010). However, the actual realisation of the previously applied projects is lower than expected[14] (see Figure 1, where no substantial increase of installed capacity occurs between 2007 and 2008).

Besides the SDE regulation, the government also pays extra attention to the "Energy Transition plan". Within this programme, the Dutch government collaborates directly with market players through a number of Energy Transition Platforms, which advise the government on desired and required legislation and support schemes to realise the above mentioned targets (IEA-PVPS, 2008). As part of this, a transition platform is established for renewable electricity supply (TP-DEV), including PV technology, to enable the transition towards a sustainable electricity supply (Energie+ 2007; Sinke, 2007). This initiative of the government seems to provide some intention of commitment to seriously realise the implementation of renewable energy technologies, and triggers several activities within the Dutch PV sector; for example, several solar companies are set up in the Netherlands around 2007: Scheuten Solar, FESTpv and Advanced Photovoltaic Applications BV (APA). These activities from the government and from the PV sector could form the beginning of the long awaited large-scale implementation of PV in the Netherlands.

This final period is dominated mainly by research and lobby activities. The government mainly supports R&D activities and the SDE regulation that is supposed to trigger the installation of PV panels remains too marginal with respect to its budget and too bureaucratic to really provide a boost to market formation. However, due to the growth of the global PV market and the attractive financial instruments in Germany, entrepreneurial activities continue in the Netherlands and several solar companies are set up. In this period, we observe an *Entrepreneurial Motor* that evolved around lobby and entrepreneurial activities.

5 Conclusion

After 30 years of policy efforts, PV technology has not been implemented on large scale. Throughout these years, many activities were carried out by entrepreneurs, researchers and investors; however, they do not seem to have a major impact or to lead to a momentum to move from the Entrepreneurial Motor to a System Building Motor. The main barriers are inconsistent regulations, unpredictable behaviour of the government and the lack of a clear vision for PV. After the government removed the EPR subsidy in 2003, even as the global PV market was simultaneously growing, the Netherlands did not pursue consistent efforts to promote deployment. Shell Solar, and with it its human capital, moved to Germany to profit from the favourable, stable and long-term institutional conditions implemented there. The government made no effort to keep the industry in the Netherlands. The German market was a good enough substitute for the home market to keep the sector going, even in times when Dutch policy was not in favour of creating a market for solar energy. Therefore, the policy implication might be that a government may decide not to strengthen some parts of the innovation system when neighbouring countries fulfil these functions sufficiently.

However, this creates two types of risks. *First*, this strategy might lead to the build-up of a PV sector, but certainly not in reaching national sustainable energy goals, as no capacity is installed in the country itself. *Second*, only knowledge development and entrepreneurial activities related to engineering and building PV cells are kept alive. Other complementary knowledge and entrepreneurial activities are not supported, such as integration of PV in design of houses, knowledge about installation, easy net metering and services related to feedback of solar energy in the grid and so on. In short, an important part of the innovation system that is necessary to make PV an integral part of the energy system is not built up. These risks are a plea for creating a home market as an integral part of the innovation system build-up, especially because the observed consistency of stimulating R&D, much less the rest of the innovation system, is still very much in line with the 'linear model'. From this, it becomes clear that consistency in policy is not seen as a necessity for successful technology development and diffusion. However, when an innovation system perspective is the basis of policy making, then the opposite reasoning is expected. This lack of systems thinking is a major problem when we take the transition towards a sustainable energy system seriously. It takes a long time to get the innovation system build-up process going again after periods of decline. In addition, transition is only possible with high degrees of consistency regarding the creation of the right boundary conditions in which the technology in question can flourish. Policy strategies should therefore target the fulfilment of all system functions in a continuous and long-term way in order for motors of innovation to occur that contribute to the build-up of the innovation system and the implementation of the technology in question. Specifically, system functions such as guidance of the search and market formation need to be targeted by continuous and long-term efforts to gain social involvement and confidence by many insiders and outsiders.

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Notes

[1]The ISES-programme has two research themes concerning PV, one on crystalline gallium arsenide (GaAs) cells that have the potential of high efficiency (35–40%) and the other on amorphous silicon (a-Si) with low production costs and an efficiency of potentially 15–20%. The PhD thesis of one of the authors (WvS) on GaAs solar cells was realised in this ISES-programme.

[2]In Dutch: NOZ-PV, Nationaal OnderZoeksprogramma PV.

[3]In Dutch: Steunregeling voor Energiebesparing en Stromingsenergie.

[4]In Dutch: Nota Energiebesparing.

[5]R&S = Renewable Energy Systems, a subsidiary company of Shell, who took over the employees of Holec Energy Systems B.V. in 1984. In 1981 Holec Energy Systems BV was founded and produced semi-crystalline silicon panels (Verbong *et al.*, 2001).

[6]The aim is to achieve a 10% share of renewable energies in 2020. PV comes on the third place as important renewable energy technology, but its actual impact will be for the long-term (EZ, 1995).

[7]In 2000 NOVEM launched the PV-GO! rebate programme for small systems as well as PV on large buildings. PV-GO! contributes up to 25% of the system costs.

[8]In Dutch: Energie Premie Regeling.

[9]At the beginning of the century 6 programmes were active: ‘Energy Contribution Regulation’ (EPR), ’Energy Performance Advice’ (EPA), ‘Energy Investment Non Profit sector’ (EINP) ‘New Energy Research’ (NEO), ’Sustainable Energy in the Netherlands’ (DEN), and ’Environmental Quality of the Electricity Production’ (MEP). Most programmes were of short duration and ended also in this period due to the coalition agreement. (SenterNovem; DE, 2003a; Sinke *et al*., 2008).

[10]In some regions, where the utility Eneco had taken over the utility REMU, the addition of subsidies lead to the absurd situation that PV systems could be purchased for about 0.01 Euro/Wp. Due to these exaggerated subsidies and free-riding behaviour the government decided to reduce the expenditure on PV (PV-Nieuwsbrieven, 2002/2003).

[11]In Dutch: ‘Milieukwaliteit Elektriciteitsproductie’ (MEP). The MEP, introduced in 2003, is a kWh subsidy paid to domestic producers of electricity from renewable sources and CHP who feed-in to the national grid. The State guarantees the subsidy for a maximum of 10 years, though not for CHP. However, the tariff for PV was limited, lower than under the EPR which means that it is very unlikely that this regulation will increase the investments in PV and entrepreneurial activities, as the costs for PV modules will remain very high.

[12]A set of energy research and technology development programmes: The New Energy Research (NEO), Innovation Subsidy Collaboration Projects (IS), Energy Research Subsidy – Demonstration (EOS DEMO), Energy Research Subsidy – Long Term (EOS LT), Transition – Unique Opportunities Scheme (Transition UKR) (SenterNovem; Sinke *et al*., 2008). These programmes cover a full range of renewable energy technologies where PV is one of the priority areas.

[13]In Dutch: ‘Stimulering Duurzame Energieproductie’.

[14]This results from the complex administration procedures that are required when adopting PV panels and the lack of capable installers who can realise the complex installation procedures (ODE, 2009).

Appendix 1: Overview of classification scheme

Function	*Indicator*	*Sign*
Function 1: Entrepreneurial activities	Project started	+1
	Project stopped	–1
	Organisations entering the market	+1
	Organisations leaving the market	–1
Function 2: Knowledge exchange	Research projects	+1
	Technological projects	+1
	Development projects (demonstration + pilot plant)	+1

Appendix 1: Overview of classification scheme (continued)

Function	*Indicator*	*Sign*
	Desktop studies on the technology (future of PV + performance of PV–systems)	+1
Function 3: Knowledge diffusion through networks	Workshops	+1
	Conferences	+1
	Reports	+1
	Platform	+1
	Roadmap	+1
Function 4: Guidance of the search	Regulations by the government (positive expectation on PV–technology)	+1
	Deficit of government regulations (negative expectation on PV–technology)	–1
	Specific tax regimes (positive expectation on PV–technology)	+1
	Deficit of tax regimes (negative expectation on PV–technology)	–1
	Positive opinions of experts	+1
	Negative opinions of experts	–1
	Positive expectations of experts	+1
	Negative expectations of experts	–1
Function 5: Market formation	Regulation programmes	+1
	Lack of regulation programmes	–1
	Stimulation programmes	+1
	Lack of stimulation programmes	–1
	Environmental standards	+1
	Lack of environmental standards	–1
	Specific favourable tax regimes	+1
	Lack of favourable tax regimes	–1
Function 6: Resources mobilisation	Subsidies for and investments in the technology	+1
	Lack of subsidies and investments	–1
	R&D subsidy programmes	+1
	Lack of R&D subsidy programmes	–1
Function 7: Creation of legitimacy	The technology is promoted by organisations, government (awards, brochures, competitions)	+1
	Lack of promotion by organisations, government (awards, brochures, competitions)	–1
	Lobby activities for the technology	+1
	Lobby activities against the technology	–1
	Positive opinions of experts branch organisations	+1
	Negative opinions of experts branch organisations	–1
Context	General events about renewable energy, technology description, exogenous activities to TIS	No sign (0), no allocation

Appendix 2: Activity pattern of system functions

Figure 2 Activity pattern of Function 1: entrepreneurial activities (see online version for colours)

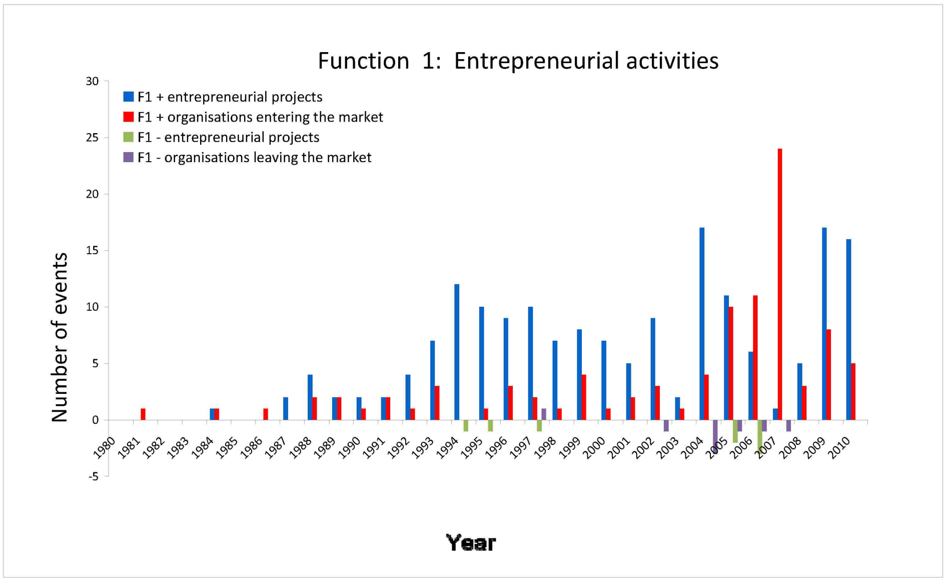

Figure 3 Activity pattern of Function 2: knowledge exchange (see online version for colours)

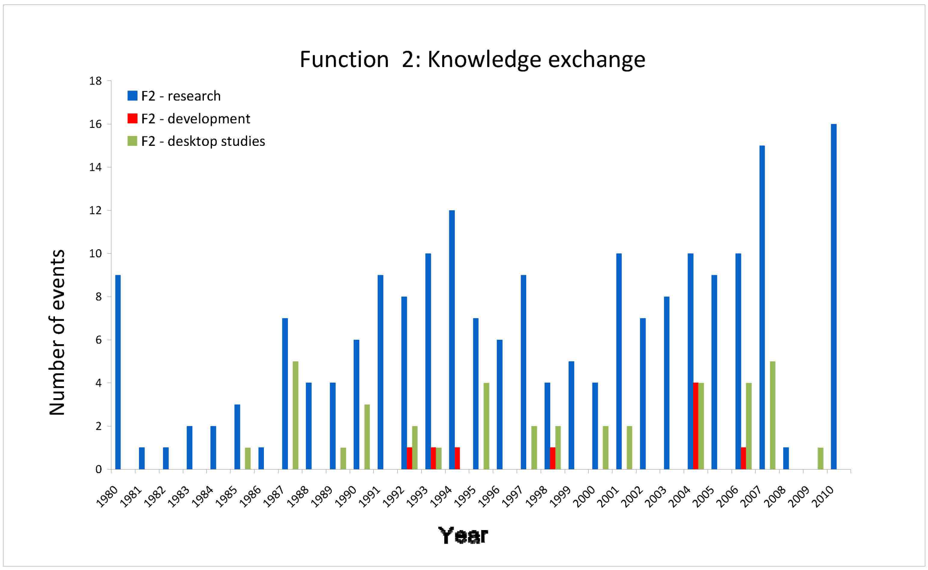

Figure 4 Activity pattern of Function 3: knowledge diffusion through networks (see online version for colours)

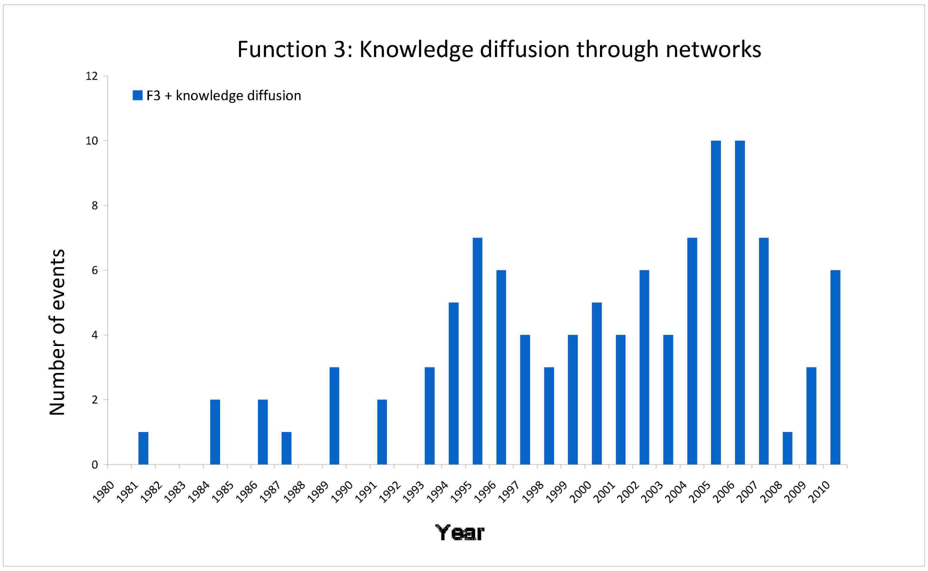

Figure 5 Activity pattern of Function 4: guidance of the search (see online version for colours)

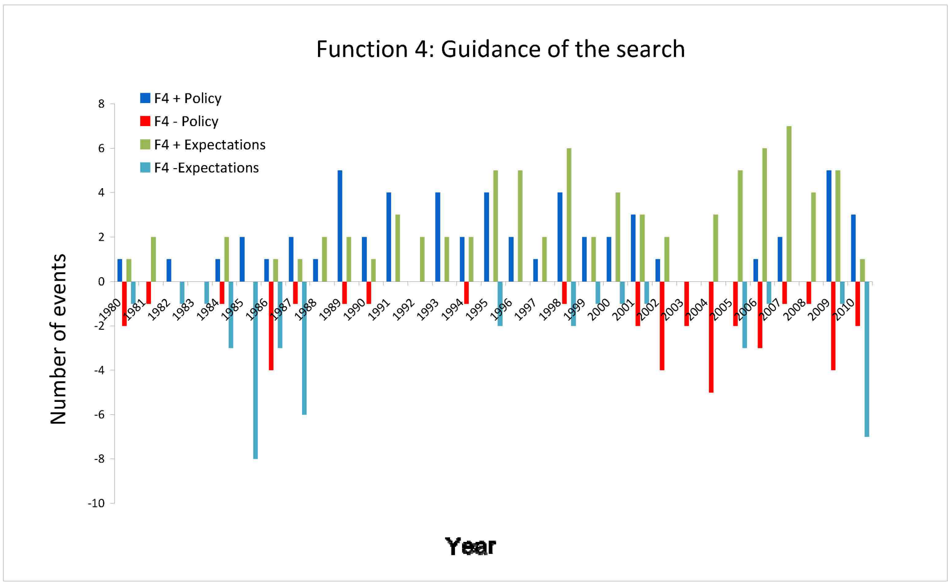

Figure 6 Activity pattern of Function 5: market formation (see online version for colours)

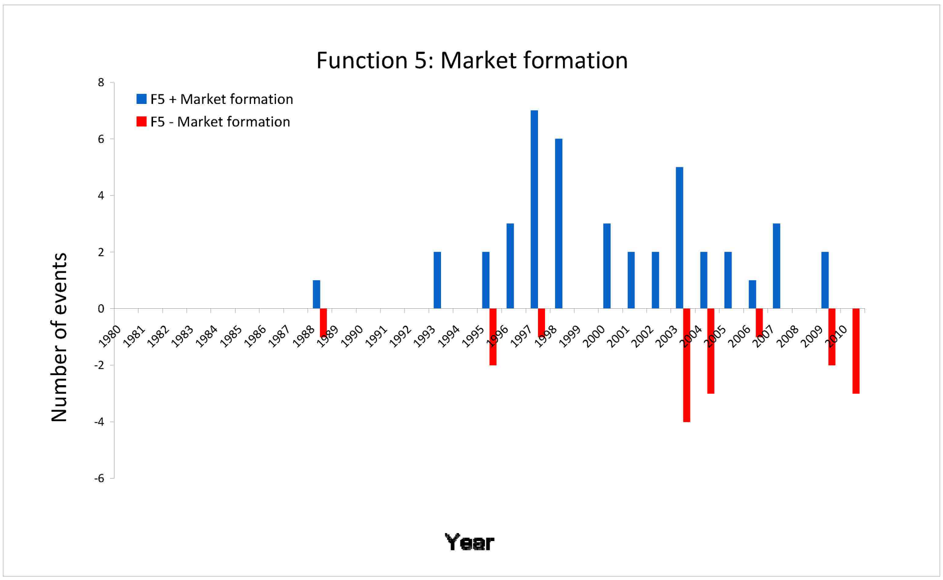

Figure 7 Activity pattern of Function 6: resource mobilisation (see online version for colours)

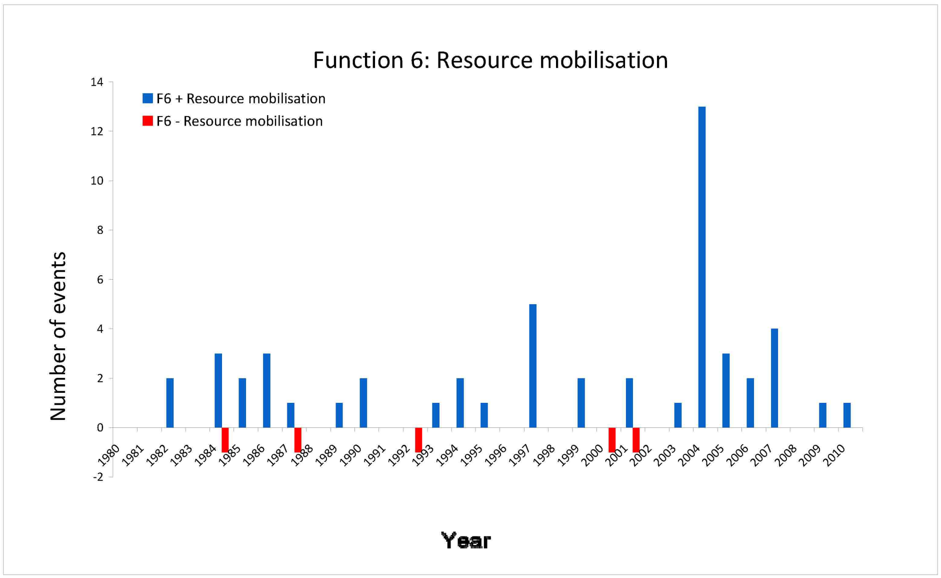

Figure 8 Activity pattern of Function 7: creation of legitimacy (see online version for colours)